May 17, 1949. H. M. BACH 2,470,738

TEMPERATURE COMPENSATED CRYSTAL UNIT

Filed Jan. 30, 1945 4 Sheets-Sheet 1

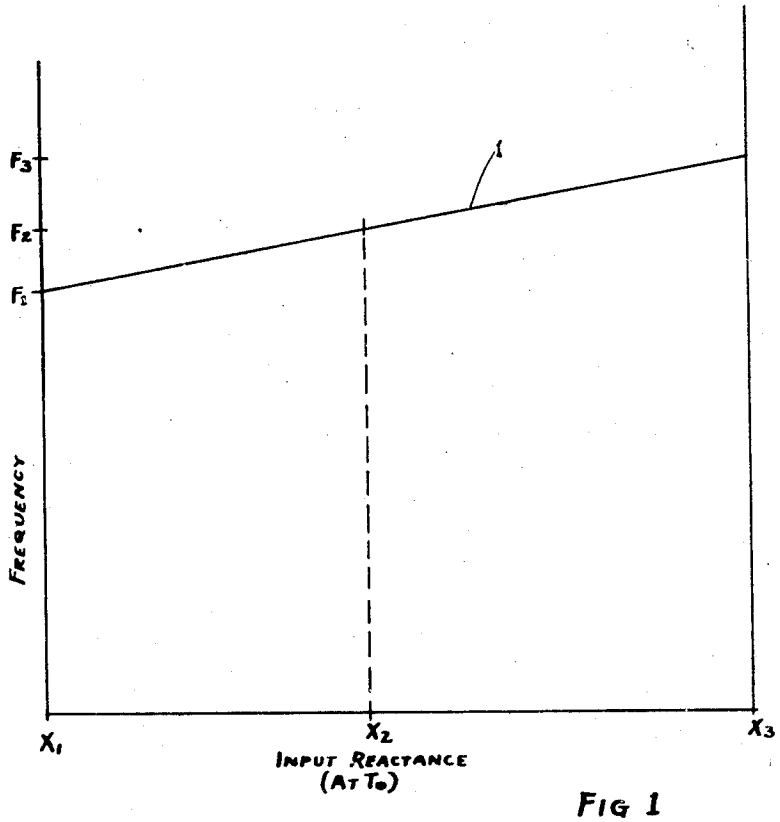


FIG 1

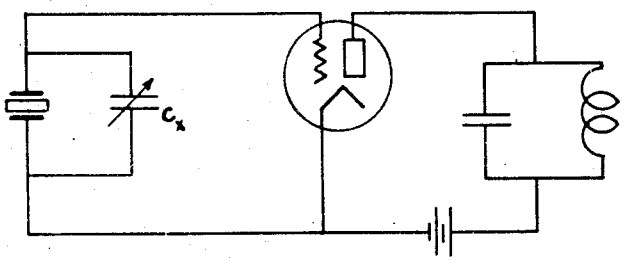


FIG. 2

Inventor
Hans M. Bach

May 17, 1949. H. M. BACH 2,470,738

TEMPERATURE COMPENSATED CRYSTAL UNIT

Filed Jan. 30, 1945 4 Sheets-Sheet 2

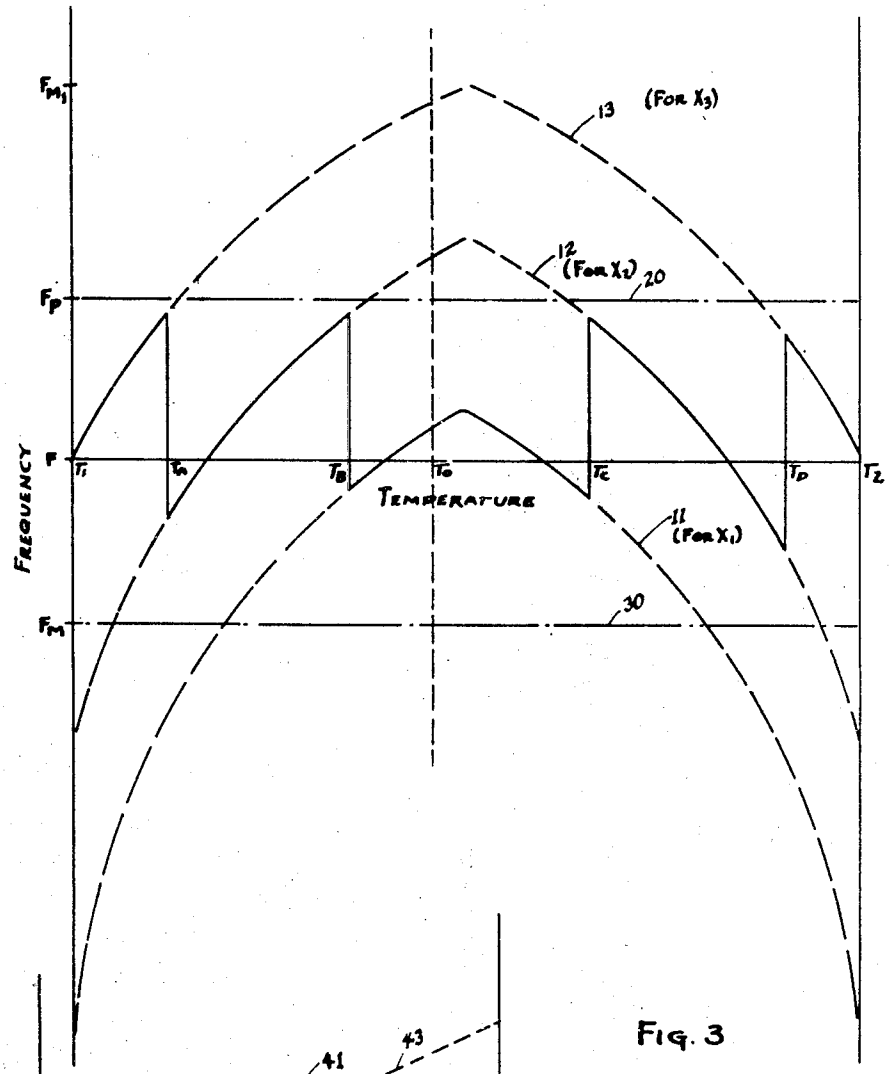


FIG. 3

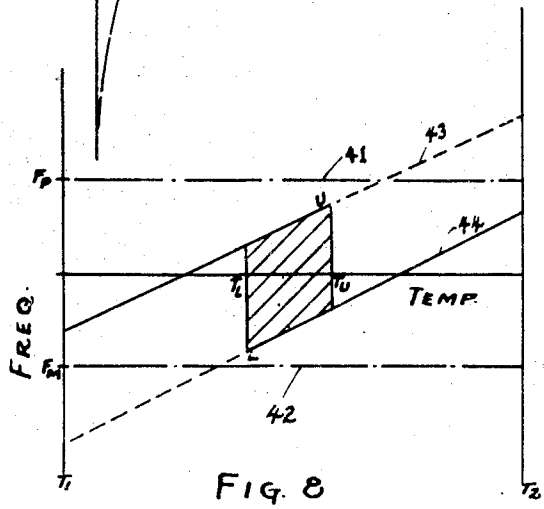


FIG. 8

Inventor
Harry M. Bach

May 17, 1949. H. M. BACH 2,470,738

TEMPERATURE COMPENSATED CRYSTAL UNIT

Filed Jan. 30, 1945 4 Sheets-Sheet 3

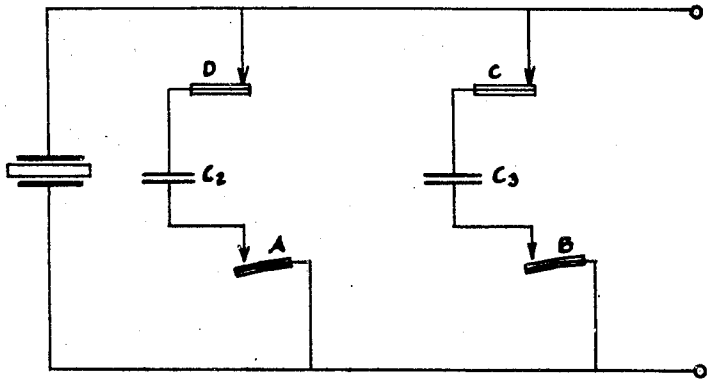


Fig. 4

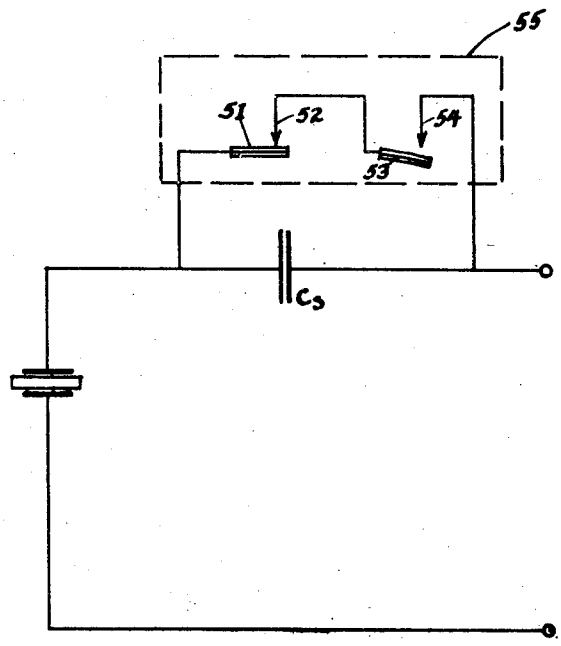


Fig. 7

Inventor

Henry M. Bach

May 17, 1949. H. M. BACH 2,470,738

TEMPERATURE COMPENSATED CRYSTAL UNIT

Filed Jan. 30, 1945 4 Sheets-Sheet 4

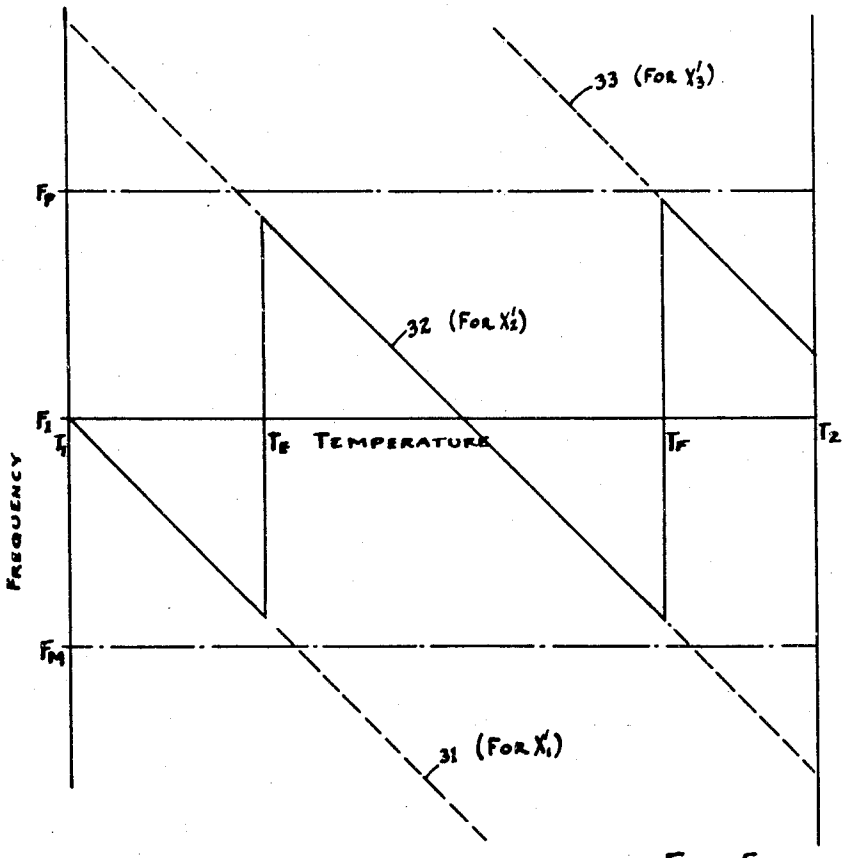


FIG. 5

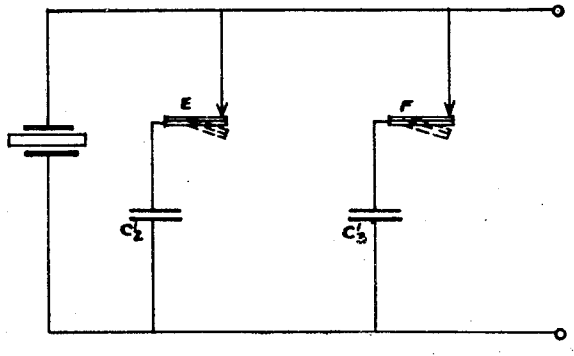


FIG. 6

Inventor
Henry M. Bach

Patented May 17, 1949 2,470,738

UNITED STATES PATENT OFFICE

2,470,738

TEMPERATURE COMPENSATED CRYSTAL UNIT

Henry M. Bach, Lawrence, N. Y., assignor to Premier Crystal Laboratories, Incorporated, New York, N. Y.

Application January 30, 1945, Serial No. 575,236

15 Claims. (Cl. 171—327)

1

This invention relates to temperature compensated crystal units, and more particularly, to a method and means for controlling the frequency drift of crystal units.

A main object of this invention is to provide an improved method and means for limiting the frequency drift of crystal units resulting from changes in ambient temperature to a very narrow range.

A further object of this invention is to provide a novel method of restricting the frequency drift of crystal units caused by changes in ambient temperature to meet close frequency drift tolerances hitherto unobtainable without the use of constant-temperature ovens.

A further object of this invention is to provide a novel structure for restricting the frequency drift of crystal units resulting from changes in ambient temperature to a narrow band of frequencies close to the nominal frequency of the crystal without the employment of special energy-dissipating equipment, such as heaters.

Further objects of the invention will appear from the following description and claims, and from the accompanying drawings, wherein:

Figure 1 is a graph illustrating the variation of crystal frequency with respect to changes in input reactance across the crystal over a portion of its oscillating range.

Figure 2 is a schematic diagram of a typical crystal oscillator circuit provided with means for varying the crystal input reactance.

Figure 3 is a graph illustrating the temperature-frequency characteristic of a typical crystal unit employing the method of temperature compensation of this invention.

Figure 4 is a schematic diagram of the crystal unit of Figure 3 provided with temperature compensating means in accordance with this invention.

Figure 5 is a graph similar to Figure 3 but illustrating the temperature-frequency characteristic of a crystal unit of different orientation than the unit of Figure 3, employing the method of temperature compensation of this invention.

Figure 6 is a schematic diagram of the crystal unit of Figure 5 provided with temperature compensating means in accordance with this invention.

Figure 7 is a schematic diagram of a modification of the crystal unit of Figure 3 provided with temperature compensating means in accordance with this invention.

Figure 8 is a graph illustrating the overlapping effect which is obtained when conventional thermostatic switches are employed in the structure of this invention.

2

One of the important electrical considerations which determines the oscillation frequency of a piezo-electric crystal operating in the usual type of crystal oscillator circuit is the input reactance as viewed from the terminals of the crystal unit. For a given crystal unit there is a fairly definite range of input reactances over which the crystal and input reactance as a network will permit oscillations to be sustained in a particular oscillator circuit.

It is a well known fact that a crystal unit designed to operate at a given frequency in one circuit will be off frequency when used in another circuit having a different input reactance by an amount which may be as much as several hundred cycles. It is also found that by placing a variable reactance, such as a variable air-dielectric trimmer condenser across the terminals of a crystal unit, the oscillation frequency may be adjusted by varying the shunt reactance, and hence, the input reactance to a desired value. Ordinarily, this procedure is employed in frequency standards to match the crystal oscillator frequency, or some multiple thereof, against a primary standard of frequency.

It is well known in the art that crystal units, even of the so-called "zero coefficient" orientations such as the AT, BT, and the like, drift appreciably over the wide range of ambient temperatures now encountered in practical usage, especially in portable ground equipment and in airborne equipment. It has therefore been necessary, where close frequency tolerances are specified, to enclose these crystal units in constant-temperature ovens, usually maintained close to a fixed temperature by a heater element requiring a source of current therefor.

To further illustrate this problem, under present methods of manufacture a BT cut crystal unit can drift plus or minus approximately 0.02% from nominal frequency over a temperature range of from −50° centigrade to +90° centigrade. Such a crystal unit would not be satisfactory for use in certain types of equipment, such as transmitters employing high multiplication factors for example, unless the frequency drift was held to a much lower variation, say, approximately plus or minus 0.005% over the temperature range. To accomplish this reduction in drift by the method of the prior art it would be necessary to enclose the unit in a constant temperature oven.

It is a prime purpose of this invention to dispense with the need for such an oven by taking

advantage of the frequency-reactance characteristic of the crystal unit in conjunction with the frequency-temperature characteristic thereof.

Referring to the drawings, Figure 1 is a graph which by way of example shows the typical variation in frequency of an oscillating crystal, connected in a conventional circuit, such as the tuned plate circuit of Figure 2, when the input reactance X, viewed from the crystal terminals, is varied from an initial value X_1 to a final value X_3 with the ambient temperature remaining constant at a value T_0.

As shown in Figure 2, the variation of crystal input reactance X may be obtained by varying the capacitance of a condenser C_X connected across the crystal. At an initial setting of condenser C_X the capacitance will be such as to present an input reactance X_1 across the crystal and the frequency will be a value F_1. As the capacitance of the condenser C_X is reduced, input reactance X increases in accordance therewith and the frequency increases in accordance with the frequency-reactance characteristic line 1 of Figure 1. Thus, at a reactance value X_2 the frequency will be F_2, and at a reactance value X_3 the frequency will be F_3. As above stated, a frequency variation of the order of several hundred cycles may thus be obtained.

Referring to Figure 3, a set of curves 11, 12 and 13 is disclosed representing the variation in frequency of a typical BT cut crystal unit between temperature values T_1 and T_2 for input reactance values X_1, X_2 and X_3, respectively. As is well known, such characteristic curves for the BT cut crystal unit are in the form of parabolas, the frequency values at the extreme ends of the temperature range being lower than the values at the intermediate portion of the range.

By using appropriate values for the input reactances the temperature characteristics may be raised or lowered with respect to each other, and as many characteristics may be obtained as there are settings of input reactance.

Let it be assumed that the normal input reactance without added shunt capacitance across the crystal is a value X_3. Then the frequency will normally vary over the temperature range T_1 to T_2 between a value F and a value F_{M_1}, the value F occurring at the cold end and at the hot end of the range. Let it further be assumed that the desired frequency drift tolerance is such that the frequency-temperature characteristic of the crystal unit is required to be held between the values F_P and F_M, as represented by the respective horizontal lines 20 and 30 in Figure 3.

In accordance with the method of this invention, the crystal unit is shifted from its original temperature characteristic 13 at an input reactance value of X_3 to a new temperature characteristic 12 at a reduced input reactance value of X_2 at a point on characteristic 13 below tolerance limit line 20 so that it will remain within the specified frequency tolerance. Another shift can be made further on in the temperature range to a still further reduced input reactance X_1 having the characteristic 11, and the process is reversed in the hot region so that the actual frequency-temperature characteristic is as shown by the full line curve of Figure 3. It is clear from Figure 3 that the frequency will be thus held between the specified tolerance limits F_P and F_M.

Figure 4 shows a schematic arrangement of one means of carrying out the above method. Connected across the crystal unit is a first shunt circuit comprising a capacitor C_2 and a pair of thermostatic switches D and A. At the starting temperature T_1 switch D is closed and switch A is open. Switch A is adapted to close at a temperature T_A, shunting capacitor C_2 across the crystal, thereby shifting the crystal characteristic from curve 13 to curve 12. A second shunt circuit is connected across the crystal comprising a capacitor C_3 and a pair of thermostatic switches C and B. At the starting temperature T_1 switch C is closed and switch B is open. Switch B is adapted to close at a temperature T_B, above temperature T_A, thereby shifting the crystal characteristic from curve 12 to curve 11. Switch C is adapted to open at a temperature T_C, shifting the crystal characteristic from curve 11 back to curve 12, and switch D is adapted to open at a temperature T_D, shifting the crystal characteristic from curve 12 back to its original characteristic 13 at the hot end of the range.

The process may be reversed, starting at temperature T_2 where switch elements C and D are open and A and B are closed. Switch D will close at temperature T_D and shift the crystal characteristic to curve 12, and switch C will close at temperature T_C, shifting the crystal characteristic to curve 11. Continued reduction in temperature causes switch B to open at temperature T_B, restoring the crystal to curve 12, and further reduction of temperature to T_A causes switch A to open, putting the crystal back on its original characteristic curve 13.

It is thus seen that by controlled automatic reduction of crystal input reactance, according to the above method and structure, the frequency of a BT cut crystal may be closely stabilized over a wide temperature range without the use of a constant temperature oven or heater.

By a similar method and analogous structure the frequency of any of the usual types of crystal units may be stabilized within close limits, and the degree of stability substantially depends on the number of thermostatically controlled reactance stages employed.

For example, in Figure 5 a series of frequency-temperature characteristics for a typical AT cut crystal is shown, having input reactances X_3', X_2' and X_1' respectively. Curve 33 is the characteristic at reactance X_3', curve 32 is the characteristic at reactance X_2' and curve 31 is the characteristic at reactance X_1'. Assuming that it is required to stabilize the frequency between F_P and F_M, as before, starting from a frequency F_1 at the cold end, a circuit is employed, as shown in Figure 6, wherein a first shunt branch contains capacitance C_2' and thermostatic switch E, closed at temperature T_1 and adapted to open at temperature T_E, and a second shunt branch contains capacitance C_3' and thermostatic switch F, closed at temperature T_1 and adapted to open at temperature T_F. Starting at the cold end temperature T_1, the crystal remains on characteristic curve 31 until temperature T_E is reached, whereupon switch E opens and the crystal shifts to characteristic 32. Upon further increase of temperature, a value T_F is reached which opens switch F and shifts the crystal to characteristic 33. It will be seen from Figure 5 that the frequency is thus maintained between the specified values F_P and F_M. As in the case of the BT crystal above considered, the stabilizing action is reversible.

Instead of employing shunt reactance units, series elements may be employed. In the embodiment represented by the schematic diagram of Figure 7, a series capacitance Cs is employed pro-

vided with a thermostatic shunting switch 55. The crystal is of the BT orientation so that in the hot or cold region it is necessary to raise the characteristic. Hence, switch 55 is provided with a first bimetal switch arm 51 cooperating with a switch contact 52 and a second bimetal switch arm 53 cooperating with a switch contact 54. Switch arm 53 is adapted to remain in the open position in the cold region and switch arm 51 is adapted to remain open in the hot region. Both switch arms remain closed in the intermediate region. Thus, thermostatic switch 55 shorts out capacitance Cs in the intermediate temperature range but opens to include capacitances Cs in series with the crystal in the hot and also in the cold regions. The input reactance is therefore a maximum at the temperature extremes and a minimum in the intermediate temperature region, as required to hold the frequency drift of the BT crystal to a reduced excursion.

Obviously, other parameters and arrangements thereof than shunt or series capacitance may be employed to control the input reactance of the crystal unit for temperature drift compensation. The method of this invention contemplates the use of either capacitance or inductance arranged in networks adapted to provide specific characteristics as required. Furthermore, continuous variation of capacitance or inductance responsive to temperature variation may be employed, by using spiral wound thermostat members, for example, connected so as to rotate variable condenser shafts or to actuate movable inductor cores, to provide the desired compensation.

The thermostatic switches may be included in the crystal holder together with the reactance elements and may be provided with appropriate adjusting means, such as adjustable screw contacts which are known in the art for setting the temperature values at which the circuits controlled thereby are opened or closed.

Consideration must be given to the fact that the usual bimetal thermostat will overlap by a few degrees in its temperature response in one direction of temperature change with respect to its temperature response in the other direction of temperature change. Therefore, the adjustment of the contact points must be such that the overlapping region, as indicated by the shaded area in Figure 8, will be located between the upper frequency limit line 41 and the lower frequency limit line 42. Thus, for increasing temperature, the frequency characteristic will move along line 43 to the right until point U is reached, whereupon the bimetal thermostatic switch will shift the characteristic to line 44, whereas, for decreasing temperature the characteristic will move along line 44 to the left until point L is reached, whereupon the switch will shift the characteristic to line 43. Between the temperatures T_L and T_U the crystal may be on either characteristic 43 or 44. The shaded area may, of course, be reduced by making the thermostatic switch more sensitive.

A further simplified embodiment of this invention which would be effective to reduce the frequency variation of the conventional BT cut oscillator plate would consist of designing the plate for compliance with the reduced drift tolerances at the intermediate portion of the frequency-temperature characteristic and providing a shunt capacitance across the plate with a pair of thermostatic switch elements in series therewith. One switch element would be adapted to open at a temperature adjacent the low end of the temperature range and the other switch element would be adapted to open adjacent the high end of the range. This would lift the drooping portions of the BT characteristic adjacent the temperature extremes to bring the plate within frequency tolerance at said extremes. It is of course understood that both thermostatic switches would remain closed over the intermediate portion of the temperature range.

Although methods have been described above for changing the input reactance of the crystal unit to compensate for frequency changes due to temperature changes, it is apparent that since any changes in frequency may, in general, be compensated for by inverse changes in electrical loading of the oscillating crystal, the compensation may be accomplished by changing the resistance component of the crystal input impedance instead of the reactance component. Therefore, it is contemplated that this invention includes thermostatic control of shunt or series resistances as well as shunt or series reactances, reactance networks, or networks including both resistance and reactance. This invention further contemplates the application thereof to crystal units of the air-gap, pressure-mounted, plated and other known types of mountings of oscillator plates.

While certain specific embodiments of the method and means of compensating for crystal frequency drift caused by temperature change have been disclosed in the foregoing description, it will be understood that various modifications within the spirit of the invention will occur to those skilled in the art. Therefore, it is intended that no limitations be placed on the invention other than as defined by the scope of the appended claims.

What is claimed is:

1. The method of limiting the frequency variation with temperature of a piezo-electric vibratory plate comprising the steps of decreasing the input impedance of the plate when the frequency rises above a first upper limit value as a result of temperature changes, and increasing the input impedance when the frequency drops below a second lower limit value as a result of other temperature changes.

2. The method of limiting the frequency variation with temperature of a piezo-electric vibratory plate having a frequency-temperature characteristic which would normally cause the frequency to exceed given limits of variation, comprising the steps of decreasing the input impedance of the plate when the frequency rises toward the upper limit of variation, and increasing the input impedance when the frequency decreases toward the lower limit of variation.

3. The method of limiting the frequency variation with temperature of a piezo-electric vibratory plate having a substantially linear frequency-temperature characteristic over its specified temperature range, comprising the steps of increasing the input impedance of the plate when the frequency decreases toward the lower limit of frequency variation, and decreasing the input impedance of the plate when the frequency rises toward the upper limit of frequency variation.

4. The method of limiting the frequency variation with temperature of a piezo-electric vibratory plate having a frequency-temperature characteristic which would normally cause the frequency to exceed specified limits of variation over the temperature range, comprising the steps of decreasing the input reactance of the plate when the frequency rises toward the upper limit

of variation, and increasing the input reactance of the plate when the frequency decreases toward the lower limit of variation.

5. An oscillator circuit comprising a piezo-electric oscillator unit and an oscillation generator whose frequency is controlled by the frequency of the piezo-electric unit, said piezo-electric unit having a frequency-temperature characteristic normally causing a frequency variation over a specified temperature range, means for limiting the frequency variation with temperature to a range between an upper limit of frequency and a lower limit of frequency comprising means responsive to temperature changes for increasing the input impedance of the circuit with respect to the piezo-electric unit when said characteristic decreases toward said lower limit and decreasing said input impedance when said characteristic rises toward said upper limit.

6. A piezo-electric crystal unit comprising a vibratory piezo-electric plate having a frequency-temperature characteristic normally causing a variation in frequency of the plate over a specified temperature range, and means for limiting the frequency variation with temperature of the plate between an upper limit of frequency and a lower limit of frequency, comprising means responsive to temperature changes for increasing the impedance of the crystal unit when said characteristic drops toward said lower limit and decreasing the impedance of the crystal unit when said characteristic rises toward said upper limit.

7. An oscillator circuit comprising a piezo-electric oscillator plate and an oscillation generator, said plate being connected to said generator so as to control the output frequency of the generator in accordance with the oscillation frequency of the plate, the frequency of the plate having a normal variation over a specified temperature range, means for limiting the frequency of the plate to a specified variation over said specified temperature range less than said normal variation comprising means responsive to changes in temperature normally causing a decrease in frequency for increasing the input impedance of the oscillation generator with respect to said plate when the frequency decreases toward the lower limit of said specified variation, and means responsive to changes in temperature normally causing an increase in frequency for decreasing the input impedance of the oscillation generator with respect to said plate when the frequency rises toward the upper limit of said specified variation.

8. In an oscillator circuit comprising a piezo-electric oscillator plate and an oscillation generator, said plate being connected to said generator so as to control the output frequency of the generator in accordance with the oscillation frequency of the plate, the frequency of the plate having a normal variation over a specified temperature range, means for limiting the frequency of the plate to a specified variation over said specified temperature range less than said normal variation, comprising a network connected in said oscillation generator, said network comprising means responsive to changes in temperature normally causing a decrease in frequency of said plate for increasing the input impedance of said generator with respect to said plate when the frequency of the plate decreases toward the lower limit of said specified variation, and further means in said network responsive to changes in temperature normally causing an increase in frequency of said plate for decreasing the input impedance of said generator with respect to said plate when the frequency of the plate rises toward the upper limit of said specified variation.

9. A piezo-electric crystal unit comprising a vibratory piezo-electric plate having a frequency-temperature characteristic normally causing a variation in frequency of the plate over a specified temperature range, and means for limiting the frequency change with temperature of the plate to a value less than said variation between an upper limit of frequency and a lower limit of frequency, comprising a circuit connected to the plate, said circuit comprising an impedance element and thermostatic switch means, said thermostatic switch means being adapted to operate said circuit so as to increase the impedance of the crystal unit responsive to a temperature change which normally causes the frequency-temperature characteristic to approach the lower limit of frequency variation, and to further operate said circuit so as to decrease the impedance of the crystal unit responsive to a temperature change which normally causes the frequency-temperature characteristic to approach the upper limit of frequency variation.

10. A piezo-electric crystal unit comprising a vibratory piezo-electric plate having a frequency-temperature characteristic normally causing a variation in frequency of the plate over a specified temperature range, and means for limiting the frequency change with temperature of the plate to less than said normal variation, comprising a normally closed circuit connected across the plate, said circuit comprising an impedance element and thermostatic switch means, said thermostatic switch means being adapted to open said circuit so as to increase the impedance of the crystal unit responsive to a temperature change which normally causes the frequency-temperature characteristic to approach the lower limit of frequency variation.

11. A piezo-electric crystal unit comprising a vibratory piezo-electric plate having a frequency-temperature characteristic normally causing a variation in frequency of the plate over a specified temperature range, and means for limiting the frequency change with temperature of the plate to less than said normal variation, comprising a normally open circuit connected across the plate, said circuit comprising an impedance element and thermostatic switch means, said thermostatic switch means being adapted to close said circuit so as to reduce the impedance of the crystal unit responsive to a temperature change which normally causes the frequency-temperature characteristic to approach the upper limit of frequency variation.

12. A piezo-electric crystal unit comprising a vibratory piezo-electric plate having a frequency-temperature characteristic normally causing a variation in frequency of the plate over a specified temperature range, and means for limiting the frequency change to less than said normal variation, comprising a normally open first circuit connected across the plate, said first circuit comprising a first impedance element, and a normally closed second circuit connected across the plate, said second circuit comprising a second impedance element, and thermostatic switch means adapted to open said second circuit so as to increase the impedance of the crystal unit responsive to a temperature change which normally causes the frequency-temperature char-

acteristic to approach the lower limit of frequency variation and being further adapted to close said first circuit so as to decrease the impedance of the crystal unit responsive to a temperature change which normally causes the frequency-temperature characteristic to approach the upper limit of frequency variation.

13. A piezo-electric crystal unit comprising a vibratory piezo-electric plate having a frequency-temperature characteristic normally causing a variation in frequency of the plate over a specified temperature range, and means for limiting the frequency change to less than said normal variation, comprising an impedance element connected in series with said plate, and means responsive to a change in temperature normally causing said frequency-temperature characteristic to approach the upper limit of frequency variation to short-circuit said impedance element.

14. A piezo-electric crystal unit comprising a vibratory piezo-electric plate having a frequency-temperature characteristic normally causing a variation in frequency of the plate over a specified temperature range, and means for limiting the frequency change to less than said normal variation, comprising an impedance element connected in series with said plate, a shunt circuit across said impedance element, and means responsive to a change in temperature normally causing said frequency-temperature characteristic to approach the lower limit of frequency variation to open said shunt circuit.

15. In combination, a piezo-electric crystal element having a natural frequency of vibration subject to variation with temperature, a capacitive impedance element, switching means for connecting said impedance element in parallel circuit relation with said crystal element thereby to determine the frequency of vibration of said crystal element, and thermal responsive means arranged to actuate said switching means to disconnect said capacitive element upon a predetermined variation in temperature either above or below a predetermined mean temperature.

HENRY M. BACH.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,994,228	Osnos	Mar. 12, 1935
2,137,304	Parkin	Nov. 22, 1938
2,264,764	Koerner	Dec. 29, 1941